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Eco-Efficiency

Combining Life Cycle Assessment and Life Cycle Costs via Normalization

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Abstract

Goal, Scope and Background. The eco-efficiency analysis and portfolio is a powerful decision support tool for various strategic and marketing issues. Since its original academic development, the approach has been refined during the last decade and applied to a multitude of projects. BASF, as possibly the most prominent company using and developing this tool, has applied the eco-efficiency approach to more than 300 projects in the last 7 years. One of the greatest difficulties is to cover both dimensions of eco-efficiency (costs or value added and environmental impact) in a comparable manner. This is particularly a challenge for the eco-efficiency analyses of products.

Methods. In this publication, an important approach and field of application dealing with product decisions based on the combination of Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) is described in detail. Special emphasis is put on the quantitative assessment of the relation of costs and environmental impacts. In conventional LCA an assessment of environmental impact categories is often made by normalization with inhabitant equivalents. This is necessary to be able to compare the different environmental impact categories, because of each different unit. For the proposed eco-efficiency analysis, the costs of products or processes are also normalized with adapted gross domestic product figures.

Results and Discussion. The ratio between normalized environmental impact categories and normalized costs ($R_{E,C}$) is used for the graphical presentation of the results in an eco-efficiency portfolio. For the interpretation of the results of an eco-efficiency analysis, it is important to distinguish ratios $R_{E,C}$ which are higher than one from ratios lower than one. In the first case, the environmental impact is higher than the cost impact, while the inverse is true in the second case. This is very important for defining which kind of improvement is needed and defining strategic management decisions. The paper shows a statistical evaluation of the $R_{E,C}$ factor based on the results of different eco-efficiency analyses made by BASF. For industries based on large material flows (e.g. chemicals, steel, metals, agriculture), the $R_{E,C}$ factor is typically higher than one.

Conclusions and Recommendations. This contribution shows that LCC and LCA may be combined in a way that they mirror the concept of eco-efficiency. LCAs that do not consider LCC may be of very limited use for company management. For that very reason, corporations should install a data management system that ensures equal information on both sides of the eco-efficiency coin.

Keywords: Eco-efficiency; Life Cycle Assessment (LCA); Life Cycle Cost (LCC); normalization

Introduction

Though the concept of eco-efficiency itself is not overwhelmingly complex, it needs to be specified in an useful manner for business purposes. That is, environmentally sound decision-making is subject to the same constraints as financial or any other strategic matters. Therefore, eco-efficiency should be operationalized in a way that allows a rather quick overview of the relative relevance of the service, goods, etc. in question. The following discussion proposes a normalization approach, which allows setting environmental and financial figures into relation to overall numbers while conveying separate environmental and financial numbers in one indicator.

Eco-efficiency is one of the key goals in corporate environmental management. Since its first academic development by Schaltegger & Sturm [1] and its prominent promotion by Schmidheiny [2] and the World Business Council for Sustainable Development [3], eco-efficiency has been operationalized on various levels and for many different kinds of applications. On an abstract level, efficiency applied to environmental projects may be understood in three ways [4,5]. Firstly, as an economic approach strongly related to cost efficiency; the underlying question in that context is under what conditions a given economic resource yields the maximum outcome. Secondly, eco-efficiency may be interpreted from a purely environmental view as ecological efficiency. That would describe the ratio between emissions and the service they originate from. Finally, and this is the perspective we follow here, eco-efficiency can be understood as economic-ecological efficiency. In this view, eco-efficiency is a kind of cross-efficiency linking environmental with economic issues and measuring the environmental impact added caused per monetary unit earned.

Assessing the environmental impacts of a product from cradle to grave is the key concern of LCA. An eco-efficiency analysis of products allows assessing different options to fulfill a customer benefit and includes the consideration of the whole life cycle of the products [4,5]. However, eco-efficiency requires a wider approach. As mentioned above, the economic dimension has to be integrated as well. Such an analysis is the basis required to achieve eco-efficiency goals and to implement strategic decisions [6,7].

Applied to products, the analysis of eco-efficiency becomes closely connected to LCA for the environmental part of the

ratio [8]. However, to determine the eco-efficiency of products, LCA has to be combined with LCC in order to cover both the economic and ecological dimension of eco-efficiency for the same product system boundary. In order to achieve this integration, a normalization approach is proposed in this paper. We show how to combine LCA and LCC in order to get a useful tool for taking strategic management decisions. German chemical producer BASF has used this method for over 300 projects, thus allowing a statistic evaluation of the practical relevance of normalized environmental impacts to costs.

However, further steps are required in order to ensure comparability and significance for decision-making processes [7]. The following section shows in what sense normalization is useful in that context.

Impact assessment means dividing the effect scores on impact categories of a product system by the overall magnitude of these categories. This overall figure differs per impact category, and is the contribution to the problem in question in a certain period of time. That is, normalization results in a normalized impact score profile [9]. Moreover, normalization may be used as a tool to communicate LCA outcomes [10]. Various approaches have been proposed for this normalization procedure [11]. A numerical example, carried out on an enterprise level, has been presented by Saling et al. [8]. Olsthoorn et al. [12] point out that translation of environmental information by means of indicators has to take into account that different stakeholders have different demands when it comes to indicators. Due to the variety of problems man has to face and the different extents people actually suffer from these, environmental impacts will always be a matter of subjective judgment. Decision-making, therefore, becomes easier when normalizing the impacts as it compares the contribution of a particular service with the overall environmental problem under consideration. This shall help to increase transparency of environmental performance – a postulation by [12] against the background of external users who aim to evaluate goods and services.

For the last years, corporations discovered the strategic advantages of eco-efficiency analyses [8]. In order to provide a sound decision support, the eco-efficiency analysis, as well as the LCA and LCC on which it is based, has to consider various aspects including scope and information quality [7,13]. An eco-efficiency ratio only provides a meaningful decision basis for management if the ecological and economical figures are derived from the same starting point [7], i.e. cover the same scope and are comparable. The integration of both dimensions of eco-efficiency requires a sound choice of indicators and accounting scopes.

Using the same system boundaries for LCA and LCC does not only have consequences for measurement and calculation, but also for organizational procedures in information management. Companies conducting LCC and LCA have to ensure that different departments, such as accounting, finance and environmental management, work hand in hand in order to avoid inefficient, redundant work and inconsistent data.

Since eco-efficiency is a concept not only restricted to business matters, the idea of combining economic and ecological impacts interest politicians as well. Reorganizing public environmental policy towards a more managerially oriented bureaucracy requires tools like eco-controlling for gathering information and LCA/LCC for deriving indicators. In that sense, integrating LCA and LCC via normalization opens the floor for the judgment of environmental policies according to impact categories as proposed for a New Public Environmental Management [14].

The remainder of this article is structured as follows: the method section introduces a formal explanation of how to use normalization as an integrating tool for LCA and LCC. The subsequent application section presents a quantitative and illustrative example of the proposed method, including the portfolio presentation approach. Furthermore, the discussion gives an overview of actual environment-to-cost relations and the sensitivity of the portfolio presentation approach. Finally, some conclusions will be presented.

1 Method: Operationalizing Eco-Efficiency by Integrating LCA and LCC via Normalization

The ecological assessment is made on the basis of an LCA which conforms to ISO 14040-14043 [15] with the following categories: global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), photochemical smog (POCP), solid wastes, water emissions, energy consumption, raw material consumption, land use, toxicity potential and risk potential. In this context, it is essential to point out that the function of a product constitutes the basis of a comparative analysis rather than the product itself [16]. Analogously, LCC generates cost figures related to a product in the same system boundaries as an LCA does, while focusing on its monetary impacts [17]. That is, the economic assessment is based on an LCC, which uses the same system boundaries as the LCA (see also [18]). However, apart from very narrow system boundaries, there is no such thing as a general standard which pre- or describes ways of how to conduct an LCC or to ensure comparability between different applications. Therefore, institutions conducting LCA and LCC simultaneously need to address the issue of system boundaries and time scales in order to ensure consistency and comparability.

The linking element between LCA and LCC is the normalization procedure, which originates from ISO 14042 [15]. This particular guideline provides an optional component that allows comparing the relative impacts of different environmental categories (e.g. GWP, AP, POCP, ODP, etc.). In general, normalization refers to the comparison of the overall size of category indicators with a reference information [19]. This ensures comparability and underlines the significance of the LCA impact data by normalizing with national total emissions or energy data (e.g. of a nation). The normalization procedure in this regard ensures comparability, reduces complexity and thereby simplifies decision-making. Normalization, hence, addresses the central challenge of environmental indicators as it promotes the meaning of eco-efficiency, the accurate presentation and the relevance for

the various information users [12]. Correspondingly, Sundmacher proposes normalization may be an adequate measure to compare product alternatives [20], especially in situations prior to market entry.

The normalization of LCA impact categories involves determination of the relation between the impact of the process and the total environmental impact of a country or region. In general, there is a tendency to take the system boundaries of a whole country or even a continent [21] as the reference base, since the availability of data is better than for single regions [20]. Another possibility is to normalize on the basis of the relevant industry. In fact, the choice of the reference base is a trade-off between availability of (sufficient) data and its relative relevance. As material flows of industrial production usually do not happen to solely take place in one particular country there should be a preference for supra-regional/-national reference numbers. However, one has to take into account data availability as well.

Determining eco-efficiency, and bringing LCA and LCC figures in a comparable line, requires normalization of the LCC figures as well. The ratio of both normalization factors describes the environment-to-cost relation for a certain project. That is, normalization can help to integrate economical and ecological figures. As has been already stressed, the LCC's system boundaries need to coincide with those of the corresponding LCA as there is no commonly accepted definition [22]. Normalization, then, sets that specific figure into relation to a rather global figure.

The first step in order to yield that kind of integration is to calculate the normalization factor for environmental impacts. In this instance, the reference value is a country's (x) gross domestic environmental impact, although one could take any kind of region into consideration (ranging from local communities, nations to continents) (**Eq. 1**):

$$NF_{i,\alpha} = \frac{LCIA_{i,\alpha}}{GDEI_{i,x}} \cdot Cap_x \text{ [Inh]} \tag{1}$$

here measured in [inhabitants per year].

$NF_{i,\alpha}$ = Normalization factor for environmental impact i for product α (i: GWP, AP, POCP, ODP, wastes, water emissions, resources, energy, land use)
$LCIA_{i,\alpha}$ = Life cycle inventory for environmental impact i; for product α as a metric number (e.g. tons) in a certain period of time, usually per year [year]
$GDEI_{i,x}$ = Gross domestic environmental impact for i in the country x as a metric number (e.g. tons) in a certain period of time, usually per year [year]
Cap_x = Net number of capita of country x measured in inhabitants in a certain period of time, usually per year [year]

As already pointed out, it is essential to analyze a certain function rather than the product itself [23]. The same procedure is repeated for all other impact categories. The average of $NF_{i,\alpha}$, $NF_{i,\beta}$, etc. is then used as one of the calculation factors for the aggregation. The higher an $NF_{i,\alpha}$ is, the more relatively important is the environmental category for the analyzed application.

In order to determine which environmental category is more relevant, a weighted average of each normalization factor of the analyzed products is performed (**Eq. 2**). A regional social weighting factor indicates specific circumstances and pecularities accounting, for example, for scarcity of resources. Correspondingly, Sundmacher describes that the efficiency of LCA as an environmental management tool may suffer from the complexity of impact models [20].

$$EI_{\alpha} = \sum \left(WF_i \cdot NF_{i,\alpha} \right) \text{ [Inh]} \tag{2}$$

$EI_{\alpha:}$ = Environmental impact of product α
WF_i = Regional social weighting factor ($\sum WF_i = 100\%$)

At that point, it must be stressed that the above-described procedure is only allowed as a first step for the integration of LCC and LCA. It must be kept in mind that the assessment of only the environmental data in the above-mentioned method is meaningless. If only the environmental impact has to be assessed, ISO 14040 ff. would have to be strongly recommended.

An ecological efficiency analysis, which only refers to an LCA, would only approach environmental problems related to specific units of a product. Actual economic processes would not be involved [23]. Therefore, the next step in evaluating eco-efficiency is the determination of the costs of a product system. With reference to Reich [22] the henceforth used LCC term shall be understood as financial life cycle costing, which implies accounting for the present values of costs (i.e., for instance, operative and decommissioning costs), appearing throughout the entire life cycle of a particular service generated from a product and within the same system boundaries as of the LCA. These life cycle costs will then be set into relation to the gross domestic product of the considered region (e.g. Germany, see **Eq. 3**). One could argue that these numbers have to be calculated for different categories as well. However, this is already captured by the LCC approach itself. In contrast to LCA, the common unit money enables the analyst to derive one figure. Accordingly, the cost normalization factor is:

$$NF_{C,\alpha} = \frac{LCC_{\alpha}}{GDP'_x} \cdot Cap_x \text{ [Inh]} \tag{3}$$

measured in [inhabitants per year] with:
$NF_{C,\alpha}$ = Normalization factor for the costs of product system α
LCC_{α} = Life cycle costs for product α in the currency of country x (same system boundaries like LCIA) in a certain period of time, usually per year [costs per year]
GDP'_x = Gross domestic product without financial transactions of country x (in the currency of country x), in a certain period of time, usually per year [money per year]
Cap_x = Capita of country x

This factor shows to what magnitude the product in question contributes to the GDP of a certain region. Due to its small absolute value, it is particularly meaningful for comparative purposes [8]. Following Eq. 2, an analogous ap-

proach would require taking a social weighting factor for economic facts into account as well. This could refer to goods, which produce positive externalities and are therefore of higher importance for society. However, for the sake of simplicity, this problem is ignored.

For the relation of environmental impact to economic costs, the quotient of the average environmental normalization factors and the average cost normalization factor is calculated (**Eq. 4**).

$$R_{E,C} = \frac{\left(\sum EI\right)/j}{\left(\sum NF_C\right)/j} \tag{4}$$

$R_{E,C}$ = Environment to cost relation for a complete project
j = Number of products in the project (1,2,3...)

A $R_{E,C,}$ greater than 1 implies that the environmental impact of the project is higher than its normalized costs, and vice versa. Using the normalization procedure to conduct an eco-efficiency analysis for strategic management decisions calls for an appropriate kind of visualization. For this particular reason $R_{E,C}$ and the eco-efficiency portfolio is proposed for graphical presentation. More precisely, the EI, the NF_C and the $R_{E,C}$ are used to calculate the portfolio position. For a discussion of different ways to present LCC results in a portfolio, refer to [24]. In this paper, the EI and the NF_c are normalized to the average value in a first step and that is set to 1 (**Eqs. 5, 6**).

$$PP_{E,\alpha} = \frac{EI_\alpha}{\left(\sum EI\right)/j} \tag{5}$$

$$PP_{C,\alpha} = \frac{NF_{C,\alpha}}{\left(\sum NF_C\right)/j} \tag{6}$$

$PP_{E,\alpha}$ = Environmental impact portfolio position for product α
J = Number of products under consideration
$PP_{C,\alpha}$ = Cost impact portfolio position for product α

These preliminary positions (PP) are then improved by the $R_{E,C}$ factor, in order to get a new position (PP´) in which a balance between environmental impacts and costs exists. Based on the geometric theorem of Pythagoras and on the cathetus theorem, the square root of the $R_{E,C}$ factor is used for calculating these new positions (PP'). The difference between the environmental impact portfolio position of each product to the environmental impact average is multiplied with the square root of $R_{E,C}$ and, respectively, the difference between cost portfolio position of each product to the cost average is divided by the square root of $R_{E,C}$ (**Eqs. 7, 8**).

$$PP'_{E,\alpha} = \left[\left(\sum PP_{E,\alpha}\right)/j + \left[PP_{E,\alpha} - \left(\left(\sum PP_{E,\alpha}\right)/j\right)\right] \cdot \sqrt{\left(R_{E,C}\right)}\right] / \left(\left(\sum PP_{E,\alpha}\right)/j\right) \tag{7}$$

$$PP'_{C,\alpha} = \left[\left(\sum PP_{C,\alpha}\right)/j + \left[PP_{C,\alpha} - \left(\left(\sum PP_{C,\alpha}\right)/j\right)\right] / \sqrt{\left(R_{E,C}\right)}\right] / \left(\left(\sum PP_{C,\alpha}\right)/j\right) \tag{8}$$

The corrected figures are then translated into a graphical portfolio. The horizontal axis displays the range of the cost figures and the vertical axis shows the environmental impacts. Due to normalization, the middle of both axes is always set to 1. From an eco-efficiency point of view, the most favorable products are located in the upper right corner, whereas the least favorable will be lower on the left side. Correspondingly, the distances of two products from the diagonal can expressed as differences in the eco-efficiency performance. Hence, product β in **Fig. 1** would be considered less eco-efficient than product α – in a relative sense!

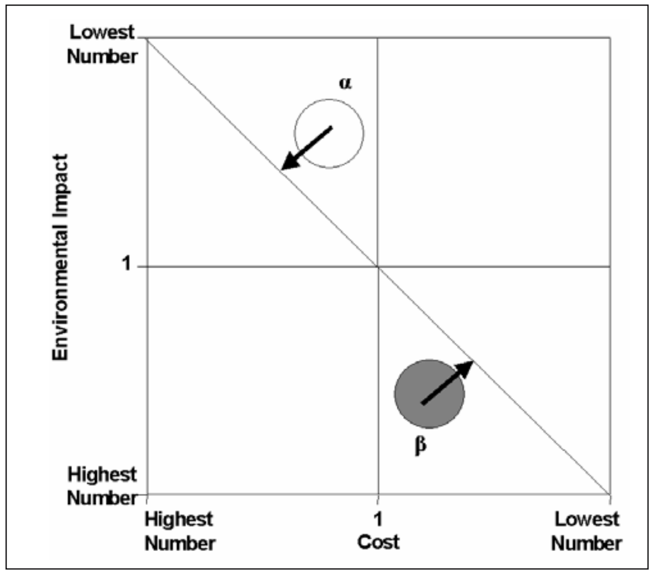

Fig. 1: Structure of an Eco-Efficiency Portfolio

Such visualization allows for a dirty-but-quick insight into the input data. As such, it converts rather complicated procedures into easy and comprehensive indicators of eco-efficiency. It is for that reason that it paves the way for eco-efficiency into strategic corporate decision-making. As Saling et al. [8] point out, a portfolio presentation not only helps to easily define research goal and alterations in the product portfolio, but also to support communication with customers and other stakeholders.

2 Results: Quantitative Example

A numerical example demonstrates the method's reasoning. The LCIA of painting a 1,000 m² wall[1] results in a GWP of 1,000 g of CO_2 equivalents for product A and 1,500 g of CO_2 equivalents for product B. Accordingly, the denominator is a rather global figure, e.g. the total GWP for Germany (1,010,000000 t) with respect to the number of inhabitants (82,000,000) [25] following Eq. 1 one obtains (**Eq. 9**).

$$NF_{GWP,A} = \frac{1000\,g \cdot 10^{-6}\,t/g}{1.010.000.000\,t} \cdot 82.000.000 = 8{,}1 \cdot 10^{-5}\ \text{Inh} \tag{9}$$

Therefore, the painting of 1,000 m² wall with product A emits as much global warming gases as $8.1*10^{-5}$ inhabitants of Germany emit on average per period of time. With product B, the global warming equivalent of $12.1*10^{-5}$ in-

[1] Because of the same durability of both products, a time period has not been taken into account.

Table 1: Numerical Example of Normalization Factors

	Product α	Product β
NF_{GWP} [Inh]	8.1 * 10^{-5}	12.1 * 10^{-5}
NF_{wastes} [Inh]	3 * 10^{-5}	1 * 10^{-5}

habitants is emitted. A similar procedure is performed to calculate the normalization factor of waste generated by painting 1,000 m² (**Table 1**).

The costs for the wall paints with paint α are 1.7 € per 1000 m² and, for product β, 1.5 € per 1000 m². The Gross Domestic Product of Germany without financial transaction is 900·10⁹ € (**Eqs. 10, 11**).

$$NF_{C,\alpha} = \frac{1{,}7\,€}{900\cdot 10^9\,€}\cdot 82.000.000\ \text{Inh} = 15{,}4\cdot 10^{-5}\ \text{Inh} \tag{10}$$

$$NF_{C,\alpha} = \frac{1{,}5\,€}{900\cdot 10^9\,€}\cdot 82.000.000\ \text{Inh} = 13{,}7\cdot 10^{-5}\ \text{Inh} \tag{11}$$

Like **Table 2** shows $R_{E,C}$ is smaller than 1. That means that, for this example, costs are more important than the environmental impact by about a factor 2.

In the example in Table 2, the costs are, relatively speaking, more important than the environmental impact. Using Eqs. (7) and (8) yields the corresponding portfolio position. The respective numbers are presented in **Table 3**.

The new calculated values for $PP'_{E,A}$ and $PP'_{C,A}$ are then used for the positioning of α in the eco-efficiency portfolio and $PP'_{E,\beta}$ and $PP'_{C,\beta}$ for product β (**Fig. 2**).

Fig. 2 shows, for the example discussed, that both products have a similar eco-efficiency (the distance from the diagonal line). As already explained in the introduction, this distance indicates the eco-efficiency of the products as the balance between costs and environmental impacts.

Table 2: Numerical Example

	Product α	Product β	
NF_{GWP} [Inh]	8.1 x 10^{-5}	12.1 x 10^{-5}	
Nf_{wastes} [Inh]	3 x 10^{-5}	1 x 10^{-5}	**Average**
WF GWP (Germany)	see [8]		62.5%
WF wastes (Germany)	see [8]		37.5%
EI [Inh]	6.2 x 10^{-5}	7.9 x 10^{-5}	7.05 x 10^{-5}
NFc [Inh]	15.4 x 10^{-5}	13.7 x 10^{-5}	14.6 x 10^{-5}
RE,C			0.48

Table 3: Final Results

	Product α	Product β	Average
EI [Inh]	6.2 x 10^{-5}	7.9 x 10^{-5}	7.05 x 10^{-5}
PP_E	0.88	1.12	1
PP'_E	0.92	1.08	1
NF_C [Inh]	15.4 x 10^{-5}	13.7 x 10^{-5}	14.6 x 10^{-5}
PP_C	1.055	0.945	1
PP'_C	1.085	0.915	1

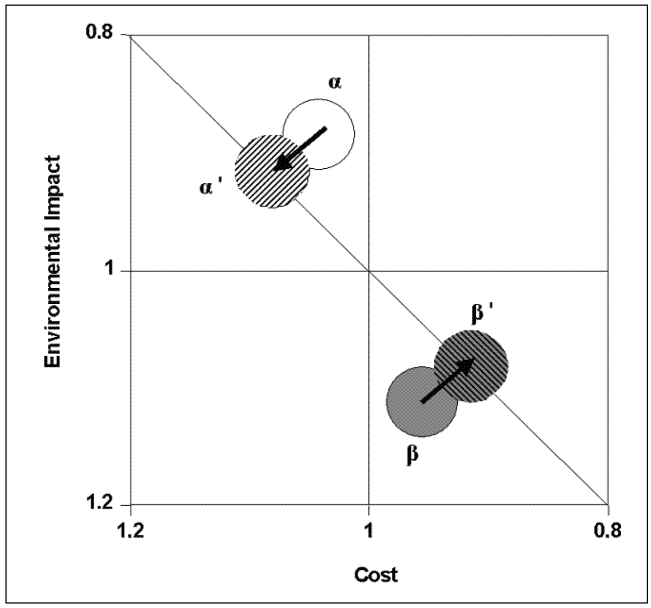

Fig. 2: Eco-Efficiency Portfolio for Numerical Example

3 Discussion

Figures on environmental impact-to-costs relation numbers have already been calculated for industrial purposes. In **Fig. 3**, the relation of normalized environmental impact to costs is shown for a number of projects evaluated by the German chemicals company BASF. It can be seen, for about 20% of the projects, that the costs, relatively speaking, are more important than environmental issues. In the other 80% of the projects, the environment is more important. The average value is about two. Such an analysis is a precondition for assessing eco-efficiency as costs directly affect the value added per unit produced and, hence, influence the ratio of environmental impact per monetary unit earned, i.e. its eco-efficiency [1,7].

These facts are not very surprising as most of the projects deal either with chemical raw materials or with processes with relatively large environmental impacts like transportation or residential appliances. In that sense, they contribute

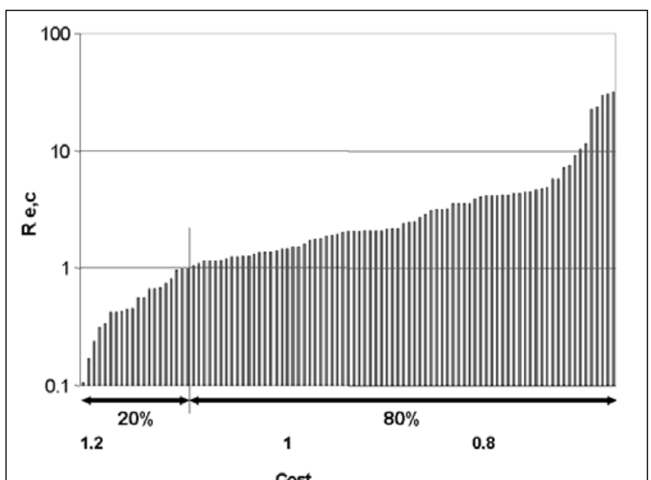

Fig. 3: Movements shown with the Eco-Efficiency Portfolio

Table 4: Influence of Environment-to-Cost Relations

	Project 1		Project 2	
	α	β	γ	δ
EI [Inh]	3	1	0.3	0.1
PP_E	1.5	0.5	1.5	0.5
NF_C [Inh]	0.5	1.5	0.2	0.6
PP_C	0.5	1.5	0.5	1.5
$R_{E,C}$	2		0.5	
	α'	β'	γ'	δ'
PP'_E	1.71	0.29	1.35	0.65
PP'_C	0.65	1.35	0.29	1.71

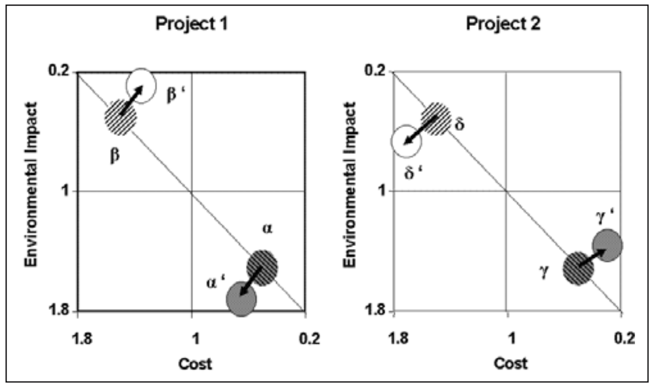

Fig. 4: Environment-to-Cost Relations for Different Projects

more to global environmental impact numbers than other products, which need less energy or smaller facilities.

For the implementation of the proposed product-oriented eco-efficiency analysis, the integration of LCA and LCC has to take data quality into consideration. The usefulness and results of an LCA strongly depend on the quality of the data and the use of inventory background data [7,13]. Using more background inventory data can result in a decreasing overall quality of information in the analysis. This is especially problematic for an eco-efficiency analysis, because data quality decreases disproportionally for the environmental and economic figures. With the use of basic inventory data, only LCA figures are affected, whereas LCC figures tend to be based on more established measurement approaches with data quality procedures.

The overall result of the eco-efficiency analysis can be improved by using more precise and more accurate (instead of average) figures. This is why the BASF method employs site-specific data wherever possible [8]. As a consequence, any product-oriented, eco-efficiency analysis should include data quality information.

A scenario analysis shows the influence of $R_{E,C}$ on the result in the portfolio presentation. Assume two different projects, one with product α and β, the other one with products γ and δ. In Project 1, the environmental impact of α is three times higher than that of β ($EI_\alpha = 3 \times EI_\beta$), whereas β results in costs that are three times higher ($3 \times NF_{C,\alpha} = NF_{C,\beta}$).

The same is assumed for Project 2 (**Table 4**).

With that assumption, the $PP_{E,\alpha}$ is the same as $PP_{E,\gamma}$ and $PP_{C,\alpha}$ is the same as $PP_{C,\gamma}$, but the $R_{E,C}$ are different for both projects. $R_{E,C}$ for Project 1 is larger than one (2) and, for Project 2 smaller than 1 (0.5). The positions in the portfolio are therefore different for both projects (**Fig. 4**).

Fig. 4 shows that for Project 1, where the environmental impact is more important ($R_{E,C}$ =2), product β is more eco-efficient (distance from the diagonal line), as the environmental benefit is much higher than the additional costs. For Project 2, product γ is more eco-efficient as the costs are much more relevant there than is the environmental impact ($R_{E,C}$ =0.5). The environmental benefit is not worth the additional costs.

4 Conclusions

The described eco-efficiency method does not provide an assessment of the absolute contribution to environmental and economic goals. Rather, it determines relative contributions to eco-efficiency and allows assessing measures, which contribute differently to eco-efficiency. The determination of the eco-efficiency of products provides the management with information necessary to achieve the largest environmental benefit per Euro spent. In other words, it allows management to achieve the largest contribution to a higher eco-efficiency and a sustainable development of the company and society. The proposed approach makes the bridge from these general considerations and shows how the eco-efficiency of product systems can be calculated in practice. This text discusses a well-developed and tested method of product oriented eco-efficiency analysis to quantitatively link LCA with LCC figures, with results shown in a portfolio. The method has been applied successfully to more than 300 projects by BASF.

The calculation of a relevance factor between normalized environmental impacts and normalized costs is a key for this analysis and the essential basis for all further eco-efficiency assessments and considerations.

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Eco-efficiency Analysis by BASF: The Method

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Abstract

Intention, Goal, Scope, Background. BASF has developed the tool of eco-efficiency analysis to address not only strategic issues, but also issues posed by the marketplace, politics and research. It was a goal to develop a tool for decision-making processes which is useful for a lot of applications in chemistry and other industries.

Objectives. The objectives were the development of a common tool, which is usable in a simple way by LCA-experts and understandable by a lot of people without any experience in this field. The results should be shown in such a way that complex studies are understandable in one view.

Methods. The method belongs to the rules of ISO 14040 ff. Beyond these life cycle aspect costs, calculations are added and summarized together with the ecological results to establish an eco-efficiency portfolio.

Results and Discussion. The results of the studies are shown in a simple way, the eco-efficiency portfolio. Therefore, ecological data are summarized in a special way as described in this paper. It could be shown that the weighting factors, which are used in our method, have a negligible impact on the results. In most cases, the input data have an important impact on the results of the study.

Conclusions. It could be shown that the newly developed eco-efficiency analysis is a new tool, which is usable for a lot of problems in decision-making processes. It is a tool which compares different alternatives of a defined customer benefit over the whole life cycle.

Recommendations and Outlook. This new method can be a helpful tool in different fields of the evaluation of product or process alternatives. It can be used in research and development as well as in the optimization of customer processes and products. It is an analytical tool for getting more sustainable processes and products in the future

Keywords: Decision making tool; eco-efficiency; eco-efficiency portfolio; ecology fingerprint; life cycle assessment (LCA) life cycle mamangement (LCM); sustainable development, metrics and measurement